

## Research into in-service deterioration of ball-rolling rolls

V Ju Rubcov<sup>1,2,3</sup>, O I Shevchenko<sup>1</sup>, A S Spirina<sup>2</sup> and N A Pankova<sup>2</sup>

<sup>1</sup> Ural Federal University named after the First President of Russia B N Yeltsin, Nizhniy Tagil Technological Institute, 59, Krasnogvardeyskaya str., Nizhniy Tagil, 622000, Russia

<sup>2</sup> EVRAZ NTMK, ul. Metallurgov, 1, Nizhniy Tagil, Sverdlovskaya oblast, 622025, Russia

E-mail: <sup>3</sup>uriylot@mail.ru

**Abstract.** This work features research findings on causes of deterioration occurring in ball-rolling rolls. The causes of such deterioration may originate not only in the excessive loads application and the use of bottleneck operating parameters but also in the specific process being implemented and the equipment used to heat-treat the rolling rolls. The deterioration occurring in roll flanges having a relatively small thickness was used to demonstrate that, to prevent the deterioration of ball-rolling roll flanges, the mill design must accommodate the minimum allowable flange widths obtained as a function of maximum allowable loads and the roll pass calculations. The next example of roll deterioration involved the use of a gas furnace to implement the heating stage of the quench hardening process for rolls made of 35KhGSA steel, which, as a result, developed roll deterioration. The use of rolls of the same steel grade, which were heat-treated in an arc furnace prior to being quenched, has been shown to deliver long-lasting positive results evidenced by many years of their operation. Rolls made of 5KhNM steel have also been shown to respond well to the heat treatment preceding the quenching process, but this time, the treatment was implemented in a gas furnace.

### 1. Introduction

The one component of a ball-rolling mill which is most susceptible to deterioration is the forming tool comprising: rolls and guides. Currently, the operating life cycle prescribed for a set of rolls before they require remachining (calculated in terms of cumulative output) is set at 600–2000 t depending on the section design being obtained and the roll pass design being used. The roll operates via flange penetration into the material, so it is the flange surface that is most susceptible to wear. However, roll failures may arise not only due to reaching of critical wear [1], but also in the process of deterioration of roll elements. The causes of such deterioration may originate in the roll material and roll pass design being used as well as in the heat treatment and operation conditions [2]. Deterioration-induced roll failures as well as early wear and tear thereof are among the factors resulting in unscheduled downtimes and forced roll changes [3], which is what makes research into these criteria a crucial task. This article discusses the causes of deteriorations processes that occur in ball-rolling rolls and actions to be taken to prevent them.

The rarest factor which, however, can still be encountered among the causes of deterioration of ball-rolling rolls is the use of bottleneck roll pass design configurations. The main challenge facing the designers of a ball-rolling mill is to ensure that their design meets the volume-per-time constancy principle, i. e. that, as the metal travels between the rolls, the volume constrained by the roll flanges



(the neck portions included) is maintained constant at all times. According to the theory of A I Tselikov [4], rolls may be safely designed with a roll pass overfill allowance not exceeding 4 %. If the roll passes are underfilled, the metal will not come in contact with the flange, which can result in the rolled product passing over onto the bar; therefore, most roll pass configurations are initially designed with an insignificant overfill allowance. Exceeding of acceptable overfill leads to the increased roll wear, as well as to obtaining substandard balls up to occurrence of Mannesmann effect.

Another important factor to consider where deterioration is possible is the minimum thickness of the flange that projects outwardly from the roll surface and thus takes maximum loads. Scientists from Lublin University suggested several roll models where the flange thickness can increase, decrease or remain almost constant as the metal travels through the pass [6]. We also suggested our own roll design concepts featuring constant as well as variable flange width solutions equally compliant with the volume constancy requirement [7]. The most effective separation of the neck occurs when the flange width at the crossing points is minimal. However, it leads to the intensive deterioration within this zone and to further formation of strings in the rolling process. Summarizing the results obtained in research works [3, 6, 8–11], it can be confirmed that roll pass designs must be configured in such a way that the flange thickness would increase in particularly intensive zones, such as the neck separation zone. The differences between roll diameters and the effects of alternating forces that need to emerge to implement the ball twisting and neck separation process are also among the causes of the deterioration occurring in this zone. In addition, in the crossing zone, flange penetration into the metal is achieved by means of the cutoff roll only.

## 2. Research results

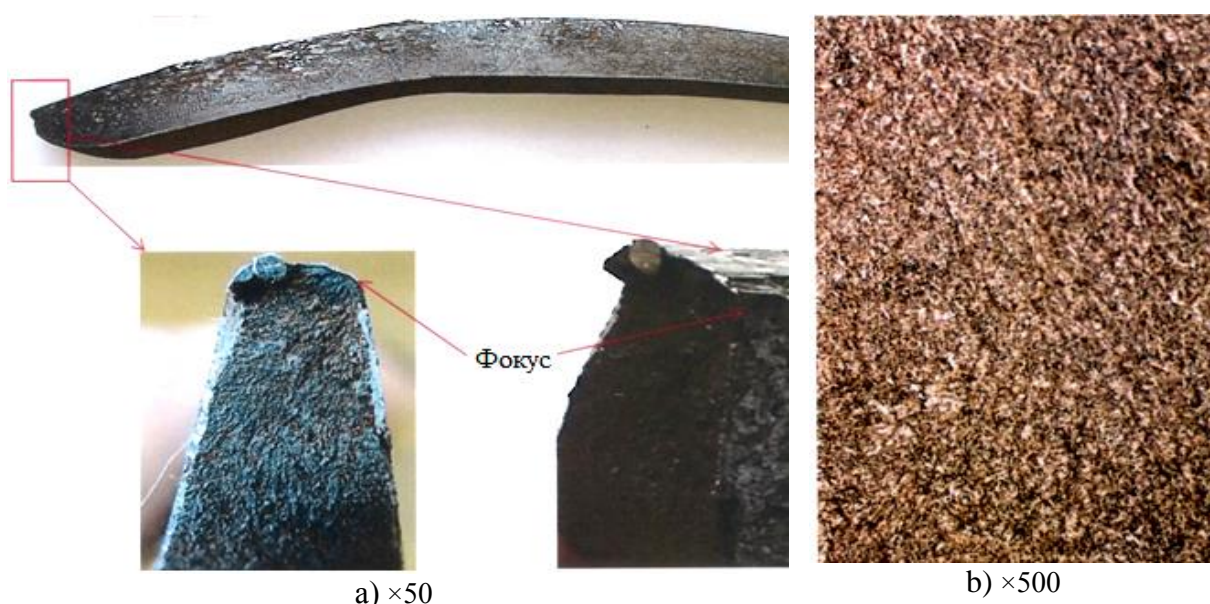
With a streamlined roll pass design solution, the overall wear and tear affecting the flanges will be characterized by the abrasion wear occurring along the working faces of the flanges. When, in particular, the choice of roll material was made in favor of 5KhNM steel and the hardness of the quench-hardened layer was relatively low (38–42 HRC), flange deterioration reached an extent where relatively large portions of it would break off.



**Figure 1.** Roll flange spalling occurring in the neck cutoff zone.

To determine the cause of such deterioration, a 30 × 250 mm sample of the deteriorated flange material that had broken off (Figure 1) from the roll (Figure 2) was taken to be put through a metallographic examination. The hardness of the sample after measurement was 31.5–38.5 HRC which is below the predefined one. The evaluation of microstructure was performed by means of Leica MEF4A optical microscope on 2 sections before and after etching process in 3% alcohol solution of hydrogen nitrate with x50–500 magnification.

The examination results showed that the base metal used in the roll flange had uniform microstructure and could be identified as tempered martensite (Figure 2, b).



**Figure 2.** Microstructure of the base metal of the flange.

The metal of the rolling work material was welded onto the side surface of the flange and also on the top of it (Figure 3, a.) followed by the separation of a portion of the roll surface, a change in the roll metal structure and the emergence of microcracks (Figure 3, b). White layer of the martensite with the depth up to 0.35 mm was found by the microchemical analysis at the site of focus (Figure 3, c). Nonmetallics, liquation of sulfur and phosphorus at the site of deterioration are absent. In view of the foregoing, it was the adhesion of the hot metal being rolled that caused the deterioration of the flange, as evidenced by the metallic pickup on the side surface and the top of the flange.

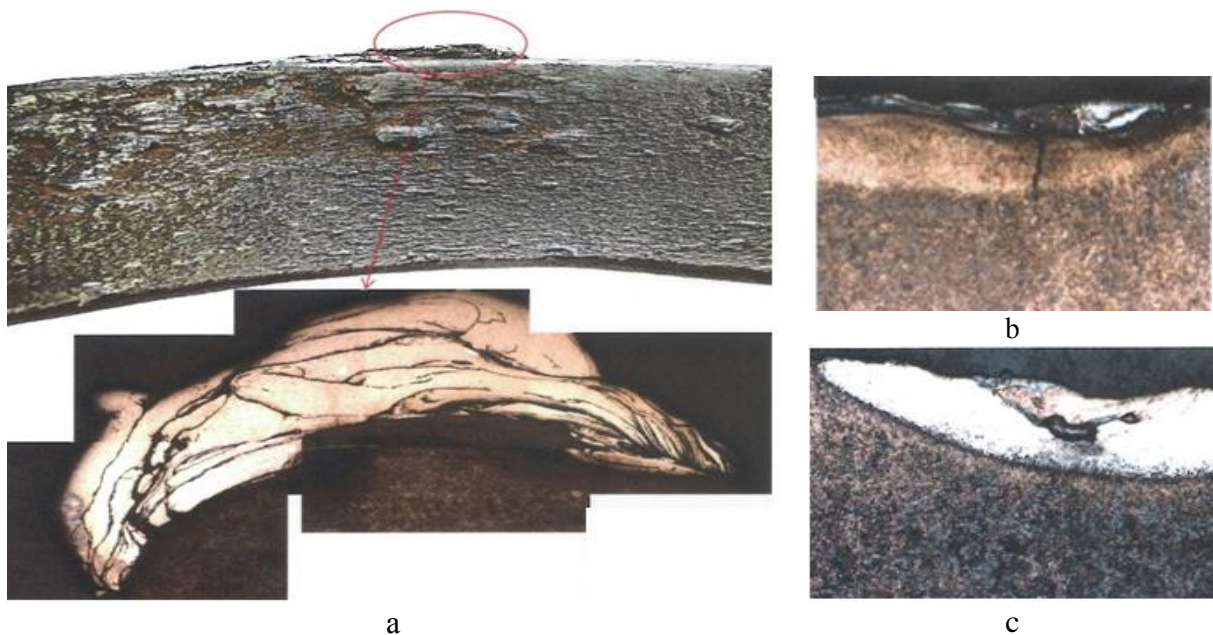
In this case insignificant load increase led to the flange overheating because of its low thickness (9.5 mm) and to further deterioration. As a result, the flange thickness is important to the design of ball-rolling rolls.

Having excluded any causes attributable to roll pass design and mill setup configurations, other possible causes of critical deteriorations may be the heat treatment conditions used for the steel grades in question. Application of 35KhGSA steel grade in the conditions of JSC EVRAZ NTMK can be a remarkable example. Bodies of ball-rolling rolls made of the mentioned steel have been regularly used during several decades under conditions of the ball section of a Large-structure Rolling Shop where heating up for heat treatment has been carried out using the arc furnace. On a trial basis, the above-mentioned grade of steel was used at the site of ball section of Rail and Beam Shop instead of the 5KhNM steel used there. Heat treatment conditions were identical to the ones for a Large-structure Rolling Shop, but due to unit feasibility the heating was carried out in the gas furnace. The complete deterioration of the roll occurred in the process of the first charging of the rolls and trial rolling. Moreover, the cracks which were the cause of the deterioration, occurred not only along the stress concentrators (keyslots, etc.) but also in parallel to the axis along the whole perimeter (Figure 4). Fractures formed on both sides of punctured part of the roll are fragile, with focuses extending from the surface of the roll-pass. Cross cracks were found on the surface of the flange roll-pass.

**Table 1.** Chemical composition of the roll sample.

Name	Element content in %							
	C	Mn	Si	Cr	Ni	Mo	S	P
Roller sample	0.347	0.93	1.25	1.33	0.042	< 0.005	0.0045	0.011
GOST 4543-2016	0.32–0.39	0.8–1.1	1.1–1.4	1.1–1.4	< 0.3	< 0.3	< 0.025	< 0.025





**Figure 3.** Microstructure of the flange metal at the side of focus of deterioration:  
a – welded metal of the rolling work material on the top of the flange (x50 magnification);  
b – microcracks and changing of the structure (x100 magnification);  
c – white layer of the martensite (x50 magnification).



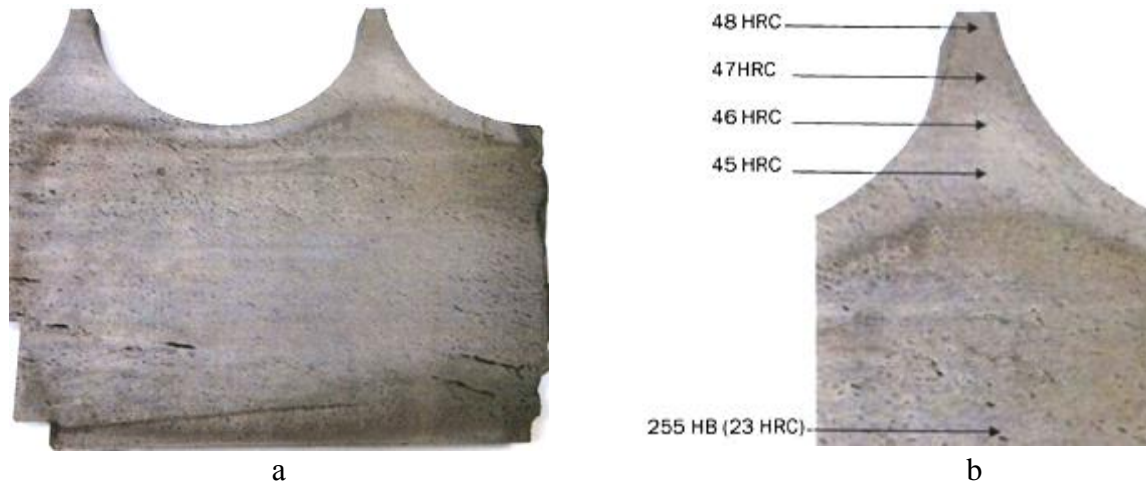
**Figure 4.** Rolling roll fracture mode.

Chemical composition of the roll metal according to the chemical composition analysis meets requirements prescribed for 35KhGSA steel according to GOST 4543–2016 [12] (Table 1).

Macroanalysis of the cross section (Figure 5, a) performed by the deep etching method in hot 50% solution of hydrochloric acid showed that the following was found in the deterioration area:

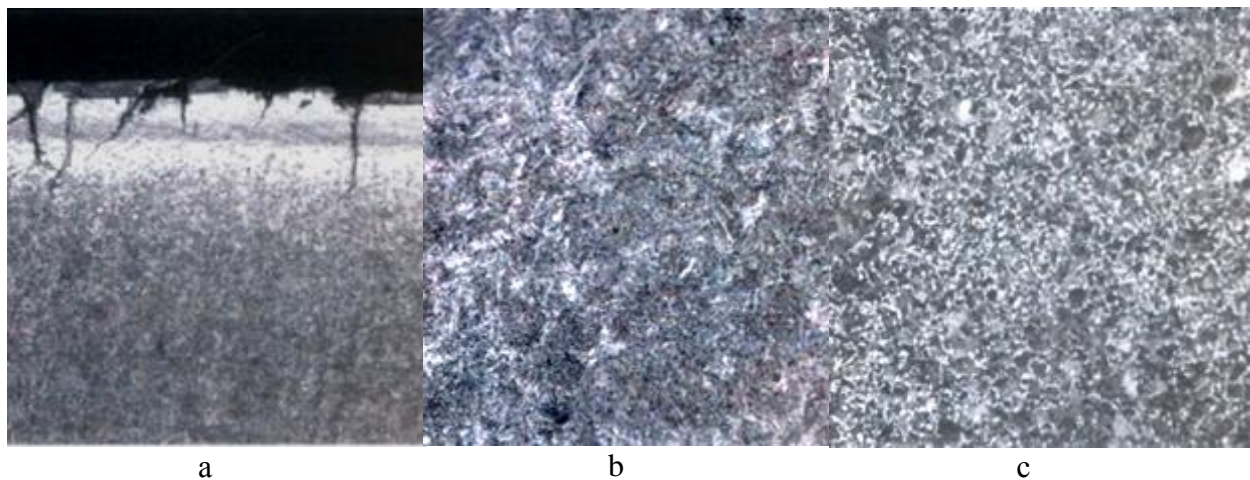
- hardened case extended along the depression of roll-pass to the depth of 10 mm,
- through hardening of the flanges of the roll-pass,
- freckle-type segregation, 3 points according to GOST 10243–75 [13].

Hardness distribution over the roll section is uneven (Figure 5, b) and is from 48 HRC with gradual decreasing to 45 HRC on the surface. Hardness of the base metal measured by Brinell scale was 255 HB.



**Figure 5.** Results of sample macroanalysis.

Microanalysis of the roll identified the presence of inadmissible decarburized layer with the depth up to 0.3 mm on the surface of the roll-pass. 15 mm deep thermal cracks and metal chipping along them were detected on one of the lateral sides (Figure 6, a).



**Figure 6.** Sample microanalysis results:

a – hardened case x100, b – hardened case x500, c – base metal x100.

Microstructure of the hardened case extending through the roll-passes represents tempered martensite with sites of retained austenite (Figure 6, b). Structure of the base metal is hypoppearlitic uneven-grained with No. 6–8 grain size according to GOST 5639–82 [14] (Figure 6, c).

As a result of above mentioned, it is possible to suggest that observation of time-temperature modes during heat treatment of ball-rolling rolls is not the only factor that has impact on their further structure including operability, but it is also equipment where heat treatment is performed. Under condition that 5KhNM steel used for ball-rolling rolls of Rail and Beam Shop is not subject to decarburization in the gas furnace, for 35KhGSA steel it was the key parameter that led to the rolls deterioration.

### 3. Conclusion

1. To avoid deterioration of ball-rolling rolls and their elements while designing apart from the type of the applied roll-pass it is necessary to count on minimum permissible flange width depending on the maximum allowable loads taken.

2. Rollers roll-pass must be calculated according to the condition of minimum possible overfill which will guarantee absence of circumferential loads if the metal is between neighboring roll-passes in the rolling process, and it will increase the rolls service life.

3. Except the structure of the ball-rolling rolls, their manufacturing technique is also important, as well as observation of heat treatment conditions and selection of equipment where it will be manufactured. For example, for a roll made of 5KhNM steel material, usage of gas furnace for heating for hardening is permissible but is impermissible for a roll made of 35KhGSA steel, as it was shown in this article.

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